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LDMOS Technology for 5 GHz Power Amplifiers

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CONTENT OF THE PRESENTATION

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  - 30V LDMOS IN CLASS AB
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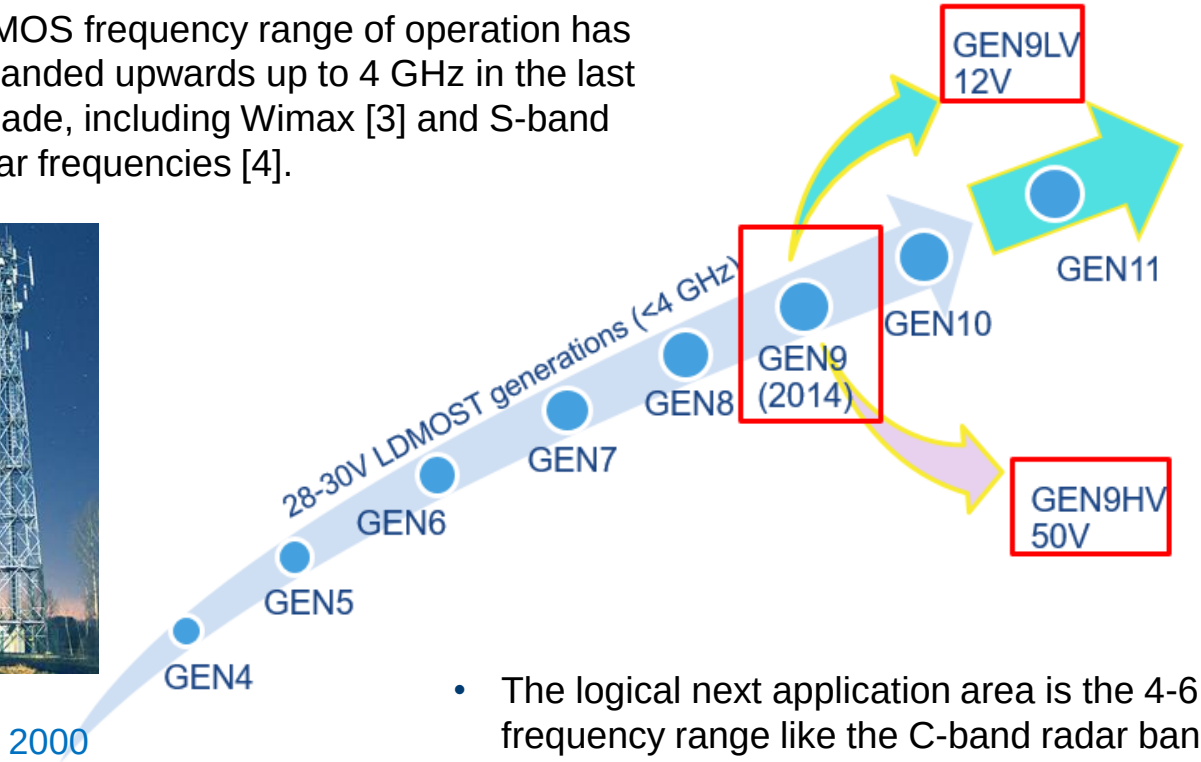
- ON WAFER LOAD-PULL RF PERFORMANCE 1-12 GHZ
  - 30V AND 50V LDMOS WITH 2ND HARMONIC OUTPUT OPTIMIZED
- LDMOS PRODUCT APPLICATION
  - C-BAND DEMONSTRATOR
- CONCLUSIONS

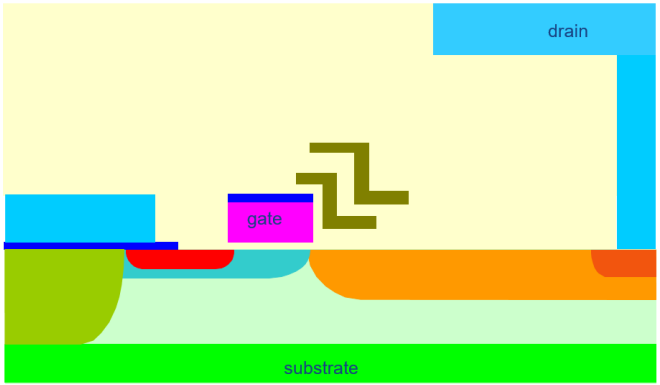
INTRODUCTION

- LDMOS frequency range of operation has expanded upwards up to 4 GHz in the last decade, including Wimax [3] and S-band radar frequencies [4].



- The logical next application area is the 4-6 GHz frequency range like the C-band radar band and future 5G Base station bands.

LDMOS DEVICE TECHNOLOGY

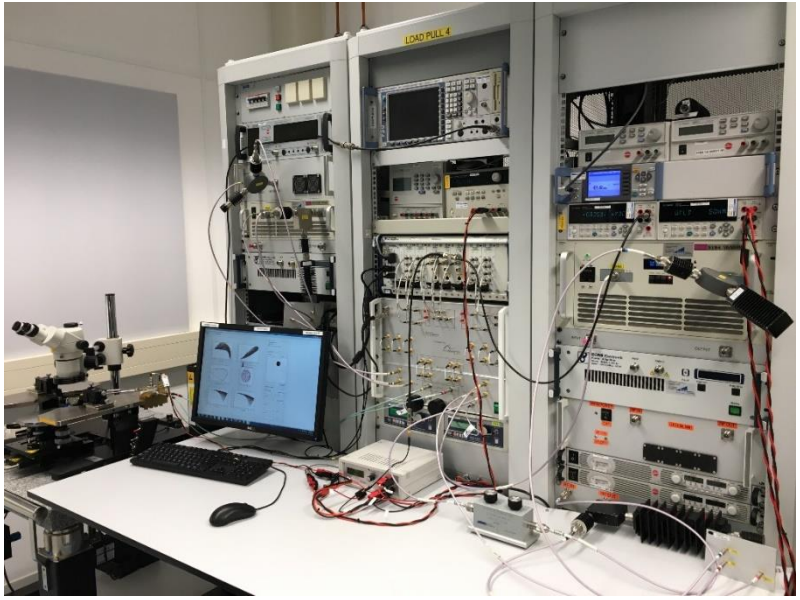


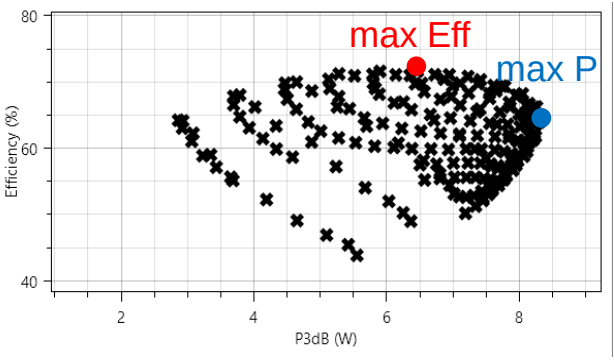
Key parameters	12V LDMOS	30V LDMOS	50V LDMOS
BVdss (V)	40	70	120
Rdson (Ω.mm)	8	12	23
Vth (V)	2.0	2.0	2.0
Cds (Vsupply) (pF/mm)	0.33	0.25	0.30
Cgs (0) (pF/mm)	0.9	0.9	0.9
Cgd (Vsupply) (fF/mm)	16	10	3
f_T (GHz)	15	15	14

- LDMOS has a proven reliability record for many applications, e.g. more than 20yr life time for base station applications.

[1] S.J.C.H. Theeuwen, J.H. Qureshi, LDMOS technology for RF power amplifiers,IEEE Transactions On Microwave Theory and Techniques (special issue on Power Amplifiers), Volume 60, Issue 6, Part 2, pp. 1755-1763 (2012)

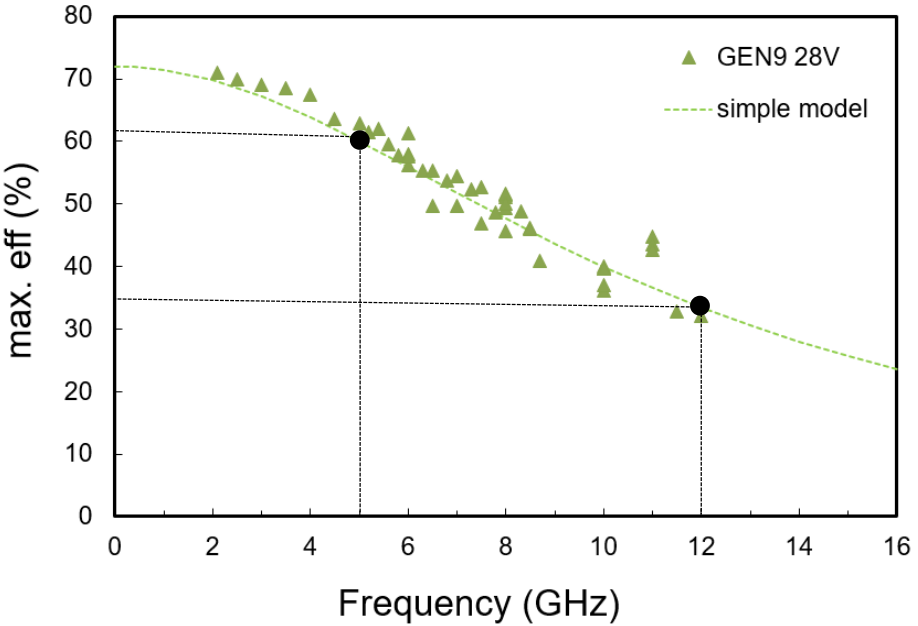
ON WAFER LOAD-PULL RF MEASUREMENTS

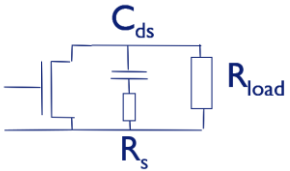




- To explore the intrinsic RF performance up to high frequencies, we use on-wafer Ground-Signal-Ground (GSG) structures with power levels of 5-10W.
- We force class (A)B operation by shorting the output harmonics up to 12 GHz.

ON WAFER LOAD-PULL: MAXIMUM EFFICIENCY IN CLASS AB

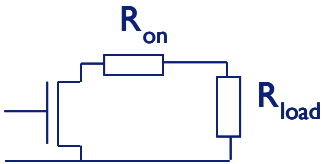




$$Eff(\%) = 78.5\% \cdot \frac{1}{1 + \omega^2 C_{ds}^2 R_s R_{load}}$$

- The frequency roll-off is due to output capacitance losses.
- 63% at 5 GHz
- 35% at 12 GHz

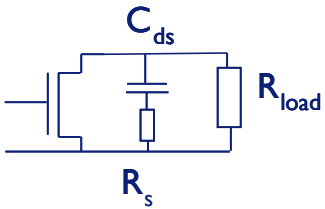
MAXIMUM EFFICIENCY THEORY



$$Eff\ (\%) = 78.5\% \cdot \frac{1}{1 + 2R_{on} / R_{load}}$$

LDMOS R_{on}: Eff=72%

$$R_{load} \sim \frac{V_{swing}}{I_{swing}} \quad or \quad R_{load} = \frac{V_{sup}^2}{2P_{dens}}$$

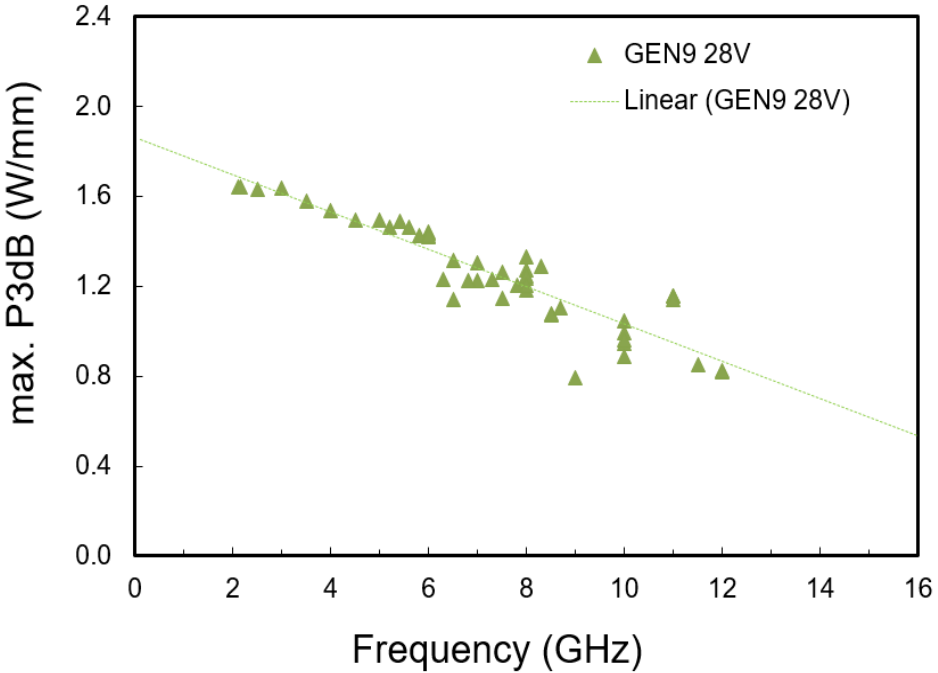


$$Eff\ (\%) = 78.5\% \cdot \frac{1}{1 + \omega^2 C_{ds}^2 R_s R_{load}}$$

Class AB: 78.5%
Class E: 100%

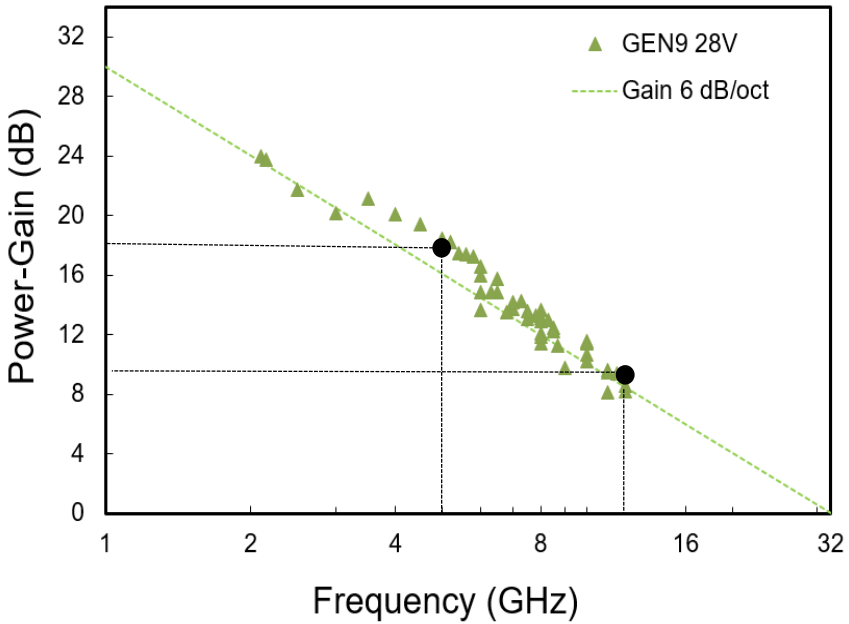
[2] F. van Rijs, and S.J.C.H. Theeuwen, “Efficiency improvement of LDMOS transistors for base stations: towards the theoretical limit,” International Electron Device Meeting IEDM, 2006, pp. 205-208

ON WAFER LOAD-PULL: MAXIMUM POWER DENSITY



- At 12 GHz, the power density is still around 1 W/mm.

ON WAFER LOAD-PULL: GAIN FOR MAX POWER LOAD



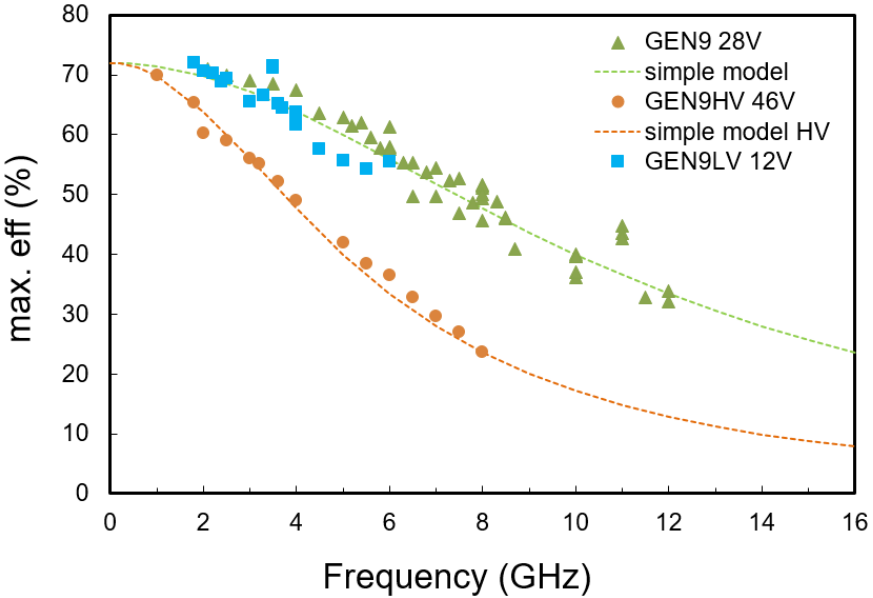
- 18dB at 5 GHz
- 10dB at 12 GHz

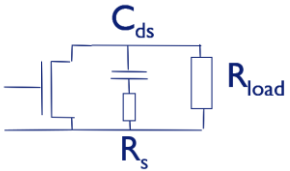
- The 0dB frequency is around 30 GHz
- This is much higher than the cut-off frequency of 15 GHz due to additional voltage/ impedance amplification.

ON WAFER LOAD-PULL RF PERFORMANCE

COMPARISON OF SEVERAL LDMOS NODES

ON WAFER LOAD-PULL: MAXIMUM EFFICIENCY IN CLASS AB

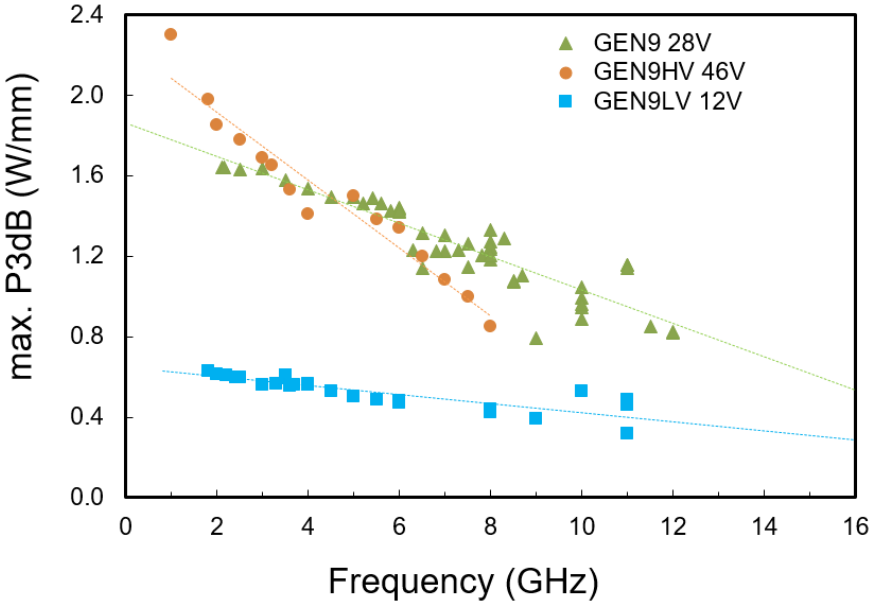




$$Eff(\%) = 78.5\% \cdot \frac{1}{1+\omega^2 C_{ds}^2 R_s R_{load}}$$

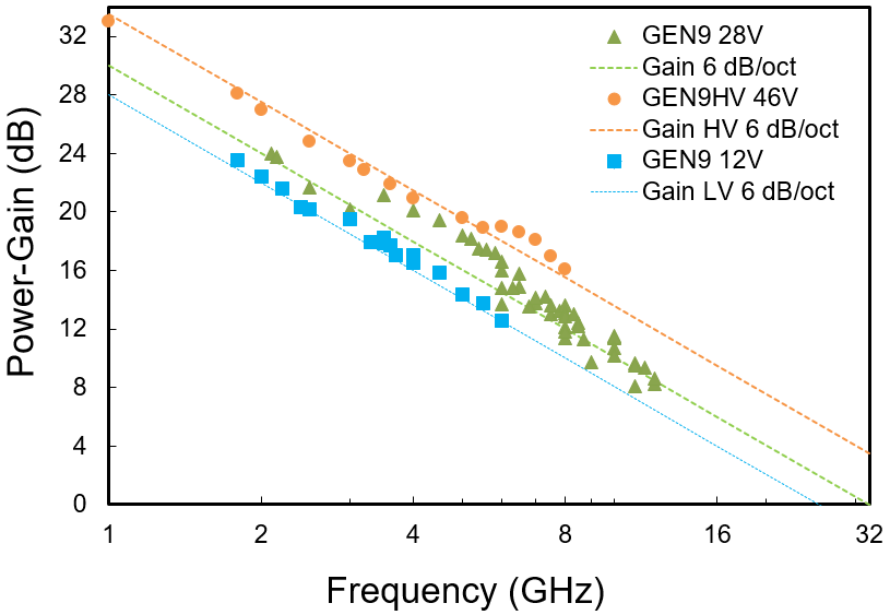
- For the frequency roll-off of the efficiency we see more losses for the 50V node.

ON WAFER LOAD-PULL: MAXIMUM POWER DENSITY



- The power density scales with supply voltage at the low frequency limit

ON WAFER LOAD-PULL: GAIN FOR MAX POWER LOAD



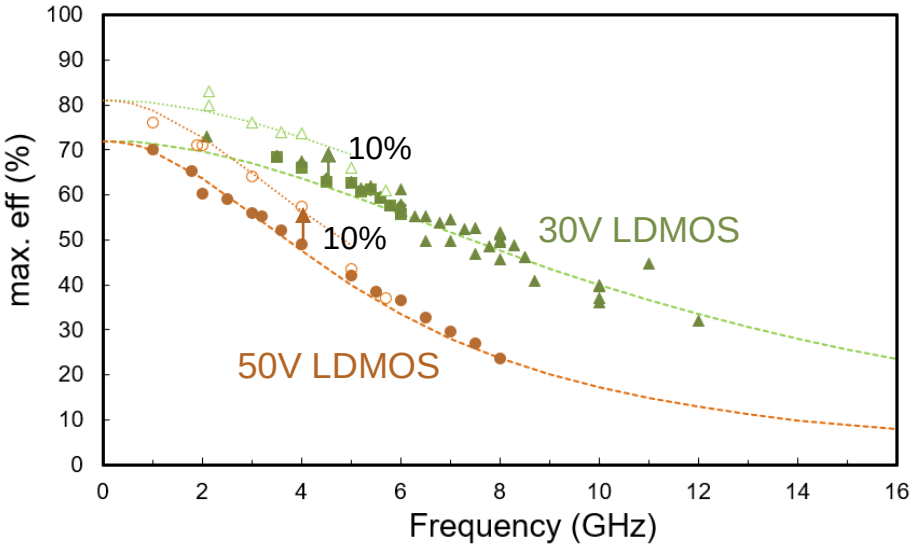
- The cut-off frequency is similar for all technologies, so the additional voltage/ impedance amplification explains the gain offset.

ON WAFER LOAD-PULL RF PERFORMANCE

OUTPUT 2ND HARMONIC OPTIMIZED FOR 30V AND 50V LDMOS

ON WAFER LOAD-PULL: MAXIMUM EFFICIENCY

OUTPUT 2ND HARMONIC OPTIMIZED FOR 30V AND 50V LDMOS

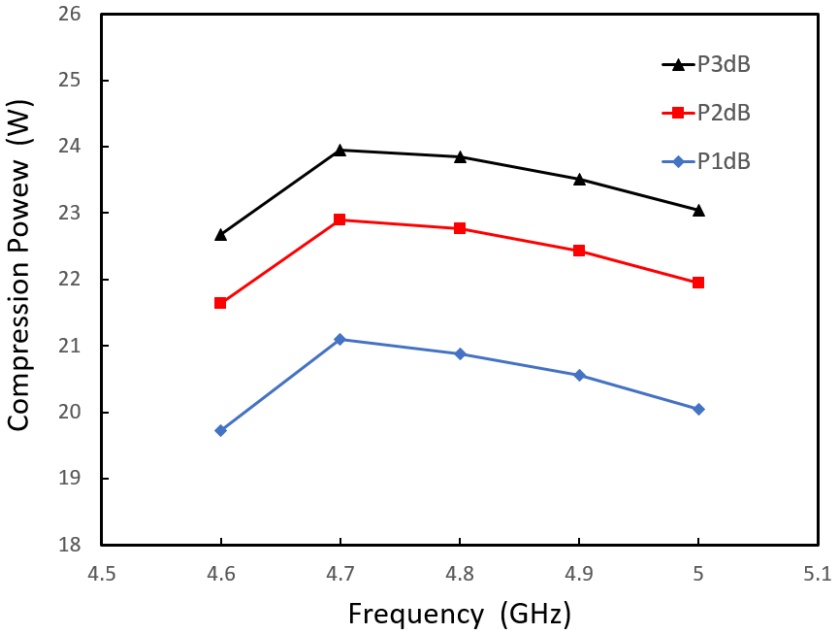


- Optimizing the second harmonic load impedance brings 10% extra efficiency for both 30V and 50V LDMOS

C-band demo BLCF9G4650L(S)-20 GEN9-30V

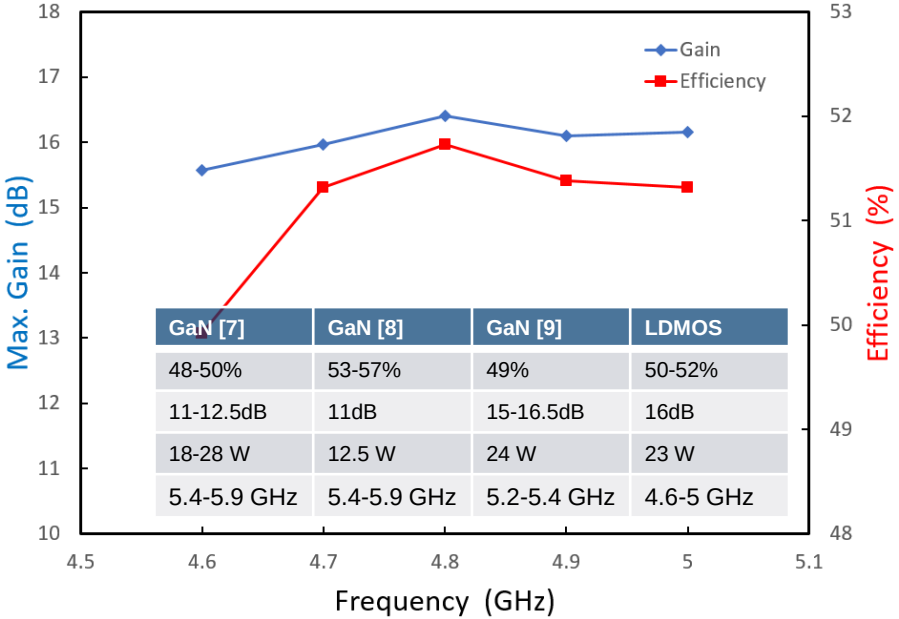
BROAD BAND DEMONSTRATOR OF >20W FROM 4.6-5.0 GHZ

C-BAND DEMONSTRATOR



- The demo is tuned for gain flatness and has over the entire band 23-24W in 3dB compression.

C-BAND DEMONSTRATOR



GaN [7]	GaN [8]	GaN [9]	LDMOS
48-50%	53-57%	49%	50-52%
11-12.5dB	11dB	15-16.5dB	16dB
18-28 W	12.5 W	24 W	23 W
5.4-5.9 GHz	5.4-5.9 GHz	5.2-5.4 GHz	4.6-5 GHz

- We achieve a maximum linear gain of 16 dB in combination with 50-52% efficiency
- If we compare the broadband performance to GaN datasheet performance numbers [7,8,9] we see for LDMOS similar efficiencies, and much higher gain

[7] Qorvo GaN data sheet T2G6003028-FS
[8] Wolfspeed GaN data sheet CGH55015F2
[9] Sumitomo GaN data sheet SGK5254-30A-R

CONCLUSIONS

- We have shown that LDMOS technology has good performance at higher frequencies 5-12 GHz, especially the 30V node.
- The intrinsic 30V LDMOS, measured by on-wafer load pull, has
  - at 2 GHz an efficiency of 72%, and 25dB gain; or 83% after 2nd harmonic optimization
  - at 5 GHz an efficiency of 63%, and 19dB gain.
  - at 12 GHz an efficiency of 35%, and 10dB gain.
- We show a 23W C-band demonstrator. In this demo circuit LDMOS shows at 4.6-5.0 GHz
  - 51% efficiency, 16dB linear gain.
- This good RF performance in combination with the proven reliability record shows the capabilities of LDMOS at 5 GHz frequencies, and in particular for C band radar applications and for the future 5G Base station applications.

Thank you for your attention

S.J.C.H. Theeuwen, H. Mollee, R. Heeres, and F. van Rijs
LDMOS technology for power amplifiers up to 12 GHz, Proceedings of the 13th European Microwave Integrated Circuits Conference, pp. 162-165 (2018)